

CE 3105 - Mechanics of Fluids Laboratory

Experiment 7: Two-Stage Centrifugal Pump Characteristics



1 Objectives

- Observe the performance of single, parallel and series connected pumps
- Learn to work with Versatile Data Acquisition System (VDAS)

2 Theory

The machine is comprised of two pumps with special arrangements of pipework and valves. It is possible to set the pump in single, parallel and series connections. Water is pumped from a reservoir through one-way valves and strainers. Water flows through inlet valves, pumps, pipework arrangement and valves before it goes through the venturi meter back to the reservoir. Pressures readings at different locations in the pipework and across the venturi meter can be observed in digital display. Flow can be calculated using the venturi meter. The pipe flow network is shown in the figure below (Figure 1):

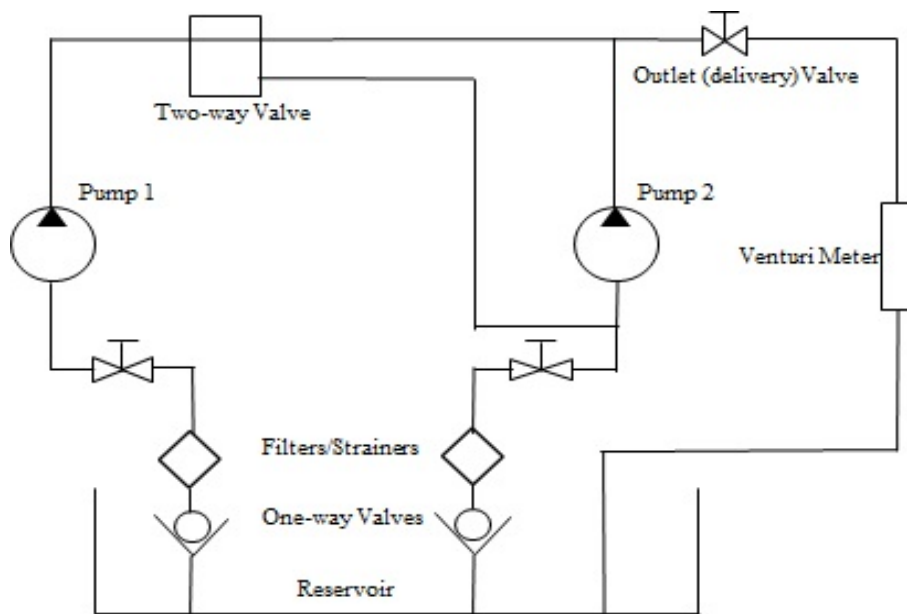


Figure 1: Pipe Flow Layout

Pressure change across the pump is the total head:

$$H = P_{out} - P_{in} \quad (1)$$

It is the difference between the outlet and inlet pressures for single test (with pump 1). For the parallel pump it is the difference between the combined outlet pressure and the average of the two inlet pressures. For the series connection, it is the difference between outlet pressure of the second pump and the inlet pressure of the first pump.

The total input power (mechanical power) is

$$W_1 = \frac{2\pi NT}{60} \quad (\text{where } N = \text{rev./min}) \quad (2)$$

The motor drive display calculates the power automatically.
The hydraulic power or the horsepower of the pump is

$$W_2 = (P_{out} - P_{in}) Q = (H)Q \quad (3)$$

The overall efficiency of the pump is

$$\eta = \frac{W_2}{W_1} \quad (4)$$

The flowrate can be calculated directly from the pressure drop along the venturi:

$$Q = C_d A_1 \sqrt{\frac{2\Delta P}{\rho \left(\frac{A_1^2}{A_2^2} - 1 \right)}} \quad (5)$$

Dimensionless analysis and similarity laws can be used to present the result of performance of a pump.

The Flow coefficient, Head Coefficient, and Power coefficient are presented in equations 6 to 8 , respectively:

$$C_Q = \frac{Q}{N_r D^3} \quad (6)$$

$$C_H = \frac{gH}{N_r^2 D^2} \quad (7)$$

$$C_P = \frac{W_2}{\rho N_r^3 D^5} \quad (8)$$

The Reynolds number based on the rotor dimension can be calculated using:

$$Re = \frac{\rho N_r D^2}{\mu} \quad (9)$$

In equations 6 to 9, it is assumed that N_r pump speed in rad/s or $N_r = \frac{2\pi N}{60}$ where N is rev/min

3 Variables/Units

Variables	Description (Units)	Variables	Description (Units)
P_{out}	Outlet Pressure (lb/ft^2)	A_1	Venturi Inlet Area (ft^2)
P_{in}	Inlet Pressure (lb/ft^2)	A_2	Venturi Throat Area (ft^2)
Q	Discharge (ft^3/s)	ρ	Density(of water) ($slug/ft^3$)
W_1	Input Power ($ft - lb/s$)	ΔP	Pressure Drop (lb/ft^2)
W_2	Output Power ($ft - lb/s$)	η	Efficiency
C_d	Coefficient of Discharge (0.97)	H	Net Pressure (Pa)
C_Q	Flow Coefficient	C_H	Head Coefficient
C_P	Power Coefficient	D	Impeller Diameter (0.37) (ft)
T	Torque ($lb.ft$)	μ	Viscosity ($lb.f.s/ft^2$)

Some Conversions:

$$1 \text{ bar} = 2088.54 \text{ lb}/ft^2$$

$$1 \text{ W} = 0.74 \text{ ft}\cdot\text{lb}/s$$

Venturi Dimensions:

$$\text{Inlet Diameter} = 0.090 \text{ ft}$$

$$\text{Throat Diameter} = 0.060 \text{ ft}$$

The actual pump system is shown in Figure 2:

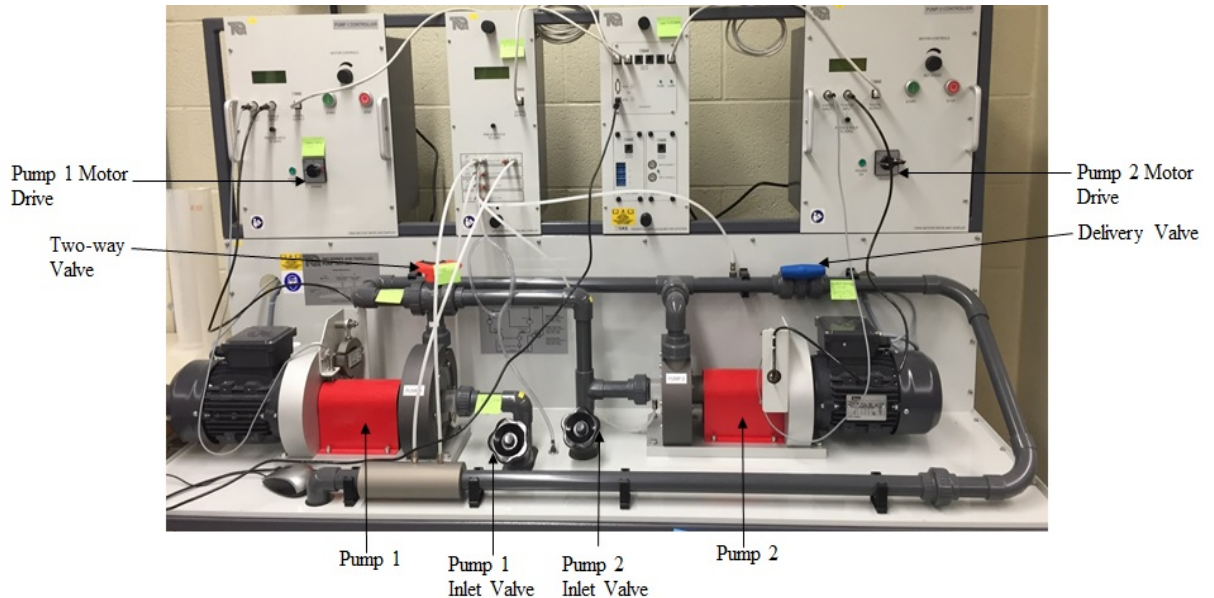


Figure 2: Two-Stage Centrifugal Pump System

4 Procedure (Single Pump- Pump 1 Only)

1. Switch off both Motor Drive Isolators
2. Fully open Pump 1 inlet (suction) and delivery valves. Make sure the Pump 2 inlet valve is closed and the two-way valve is set to the direct flow straight to the delivery pipe
3. Start Pump 1 and run it to a maximum speed
4. Bleed all pressure gauges using the bleed line
5. Set the motor speed to 3000 rev./min and make sure the delivery valve is fully open
6. Use the delivery valve to change outlet pressure, adjust the motor speed back to its initial setting and take pressure readings
7. Repeat step 6 to take 5 readings

5 Procedure (Parallel Pumps- Pump 1 and Pump 2)

1. Switch off both Motor Drive Isolators
2. Open both Pump 1 and 2 inlet (suction) valves. Make sure the two-way valve is set to the direct flow straight to the delivery pipe. Fully open the delivery valve
3. Start both Pump 1 and 2, and run them to a maximum speed
4. Bleed all pressure gauges using the bleed line
5. Set the motor speed to 3000 rev./min and make sure the delivery valve is fully open
6. Use the delivery valve to change outlet pressure, adjust the motor speed back to its initial setting and take pressure readings
7. Repeat step 6 to take 5 readings

6 Procedure (Series Pumps- Pump 1 and Pump 2)

1. Switch off both Motor Drive Isolators
2. Open Pump 1 inlet (suction) valve while closing that for Pump 2. Make sure the two-way valve is set to the direct flow straight to the inlet of Pump 2. Fully open the delivery valve
3. Start both Pump 1 and 2, and run them to a maximum speed
4. Bleed all pressure gauges using the bleed line
5. Set the motor speed to 3000 rev./min and make sure the delivery valve is fully open
6. Use the delivery valve to change outlet pressure, adjust the motor speed back to its initial setting and take pressure readings
7. Repeat the steps 6 to take 5 readings

7 Calculations

1. Plot graphs of efficiency, power input and Net Pressure against flow rate for the single, parallel and series pump settings
2. If you are using VDAS and the Digital Pressure Display for Calculation-1, use $H(\text{in Pa}) = (P_4 - P_2) * 100000$ for single pump and series pumps and $H(\text{in Pa}) = (P_4 - [(P_2 + P_3) / 2]) * 100000$ for parallel pumps
3. For single pump test, plot the dimensionless characteristics of head coefficient and power coefficient against flow coefficient. Calculate and compare the Reynolds Numbers
4. Tabulate all results.

8 Interpretation Questions (for Report)

1. For the Single Pump Test, explain the performance (relation between efficiency, head and flowrate). What is the best efficiency you think?
2. Compare the performance of series and parallel pump tests against the single pump test.
3. How does the total head curve change by parallel and series connections?
4. How does the efficiency change by parallel and series connections?
5. Do the efficiencies of this experiment match with the typical large industrial pump efficiency (which is normally about 75%)? Why or why not?

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Experiment: Two-Stage Centrifugal Pump Characteristics - Data Sheet
 Date of Experiment:, Name:.....

Experimental Data:

Temperature of water, $T =$ celsius

Water density, $\rho =$ (lb/ft^3)

Gravity, $g = 32.2$ (ft/s^2)

Single pump Test:

P_2	P_3	P_4	ΔP	Torque	Pump 1 Speed (N_1)	W_1	H	Q	W_2	η

Instructor's Signature

Series pump Test:

P_2	P_3	P_4	ΔP	Torque (1)	Torque (2)	Pump 1 Speed (N_1)	Pump 2 Speed (N_2)	Pump1 W_1	Pump2 W_1	H	Q	W_2	η

Parallel pump Test:

P_2	P_3	Avg. Inlet Pressure	P_4	ΔP	Torque (1)	Torque (2)	Pump1 Speed (N_1)	Pump2 Speed (N_2)	Pump1 W_1	Pump2 W_1	H	Q	W_2	η

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Instructor's Signature